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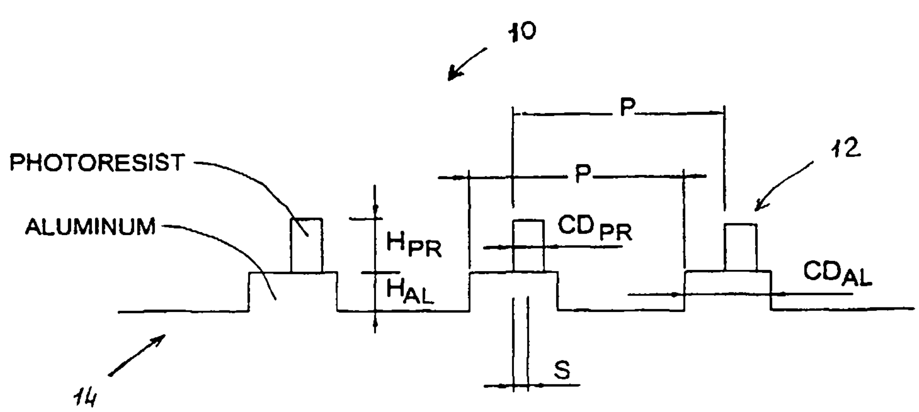
(54) Title: LATERAL SHIFT MEASUREMENT USING AN OPTICAL TECHNIQUE




(57) Abstract: The method for controlling layers alignment in a multi-layer sample (10), such a semiconductors wafer based on detecting a diffraction efficiency of radiation diffracted from the patterned structures (12, 14) located one above the other in two different layers of the sample.

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# LATERAL SHIFT MEASUREMENT USING AN OPTICAL TECHNIQUE

## FIELD OF THE INVENTION

This invention is generally in the field of manufacturing of multi-layer structures, such as semiconductor wafers and integrated circuits, and relates to an optical measuring method and system for control of layers alignment.

## BACKGROUND OF THE INVENTION

Integrated circuits are multi-layer structures produced by applying a sequence of deposition-lithography-etching steps to a semiconductor wafer. In such structures layers have to be precisely aligned with each other, which is controlled by the so-called "overlay measurement". This measurement is usually accomplished using a box-within-a-box technique consisting of the following. A rectangular frame-like structure is formed in a test site of each layer, and two adjacent layers are considered as being correctly aligned if a specific alignment between the frames on these layers is provided. Overlay defining the alignment is measured by comparing the shifts between the frames at opposite sides: determining whether the frames are precisely concentric, the smaller frame being inside the larger one (in projection).

The above technique is carried out by an ordinary optical microscope, which is capable of measuring line width with a resolution limited by resolution of optical imaging systems, usually not less than several nanometers. The current high-performance semiconductor devices, however, have features' dimensions of 0.13μm and less, and require measurements of overlay registration with the resolution of less than 1nm.

A different alignment technique is disclosed in the US Patent No. 5,216,257. According to this technique, two grating structures of different periodicity are deposited on two adjacent layers in a multi-layer structure, and a change in a moire fringe pattern caused by the superposition of two gratings is detected, being indicative of a grating alignment error.

## SUMMARY OF THE INVENTION

There is a need in the art to facilitate overlay measurements for the purpose of correct alignment of layers in a multi-layer sample (e.g., integrated circuit), by providing a novel optical method and system.

The main idea of the present invention is based on the fact that the diffraction of incident radiation from a pair gratings (or any other diffractive structures), located one on top of the other is affected by all geometrical aspects of the gratings, namely, both the parameters of each separate grating and their location relative to each other (i.e., lateral shift). According to the present invention, the lateral shift between two layers is determined by analyzing electromagnetic radiation (light) diffracted from gratings (patterned structure) of substantially the same periodicity, which are specifically arranged within a site formed by regions of two layers. To this end, scatterometry (measuring diffraction efficiency as a function of wavelength and/or angle of incidence) or ellipsometry (measuring both change of polarization amplitude and phase of the diffracted light) can be utilized. These techniques are based on the detection of the so-called "diffraction signature" of two gratings one on top of the other.

Thus, according to the invention, an effect of radiation diffraction from two patterned structures (gratings) of known periodicity located one on top of the other, caused by a lateral shift between the two patterned structures, is detected and analyzed to determine an alignment error. The patterned structures are located within a site formed by two regions of two layers, respectively. Preferably, two patterned structures (gratings) of substantially the same periodicity are used.

According to different embodiments of the invention, the following methods are used: a so-called "direct method", a method based on reference sites, and a method based on simple calibration. The direct method is based on the initial calculations of a diffraction signature using certain well-defined models. The reference sites method is based on the comparison between diffraction signatures measured in different sub-regions of the site. The simple calibration based method utilizes certain reference data previously obtained by any suitable tool to be indicative of various diffraction signatures corresponding to respective lateral shifts. These different methods require different sites prepared on the layers of a multi-layer sample.

The term *"site"* used herein signifies a location in a multi-layer sample that includes two regions one on top of the other. Such a site may be a test site located outside the features containing area if a sample.

If layers' shift along more than one axis in the sample plane is to be determined, the test site (generally, grating containing site) includes two main regions, one containing a grating structure aligned along the X-axis of the sample and the other along the Y-axis of the sample. Each region may contain several different sub-regions having different nominal shifts between the gratings. The term *"nominal"* signifies a shift of the masks used for layer manufacturing, assuming perfect masks production and zero alignment error.

Another embodiment of the test structure may contain a two-dimensional grating enabling the measurement of the X and the Y components of the lateral shift at the same site. In order to avoid the possibility to confuse between the X and the Y components several methods may be used: (a) Produce a test site whose period in the Y-axis is significantly different than the period in the X-axis (b) measure the same site several times using different polarizations (in case of polarized reflectometry) (c) measure the same site from different directions. All the above methods result in different changes to the diffraction signatures due to shifts in different directions, thus avoiding confusion.

## BRIEF DESCRIPTION OF THE DRAWINGS

In order to understand the invention and to see how it may be carried out in practice, a preferred embodiment will now be described, by way of non-limiting example only, with reference to the accompanying drawings, in which:

**Fig. 1** is a schematic illustration of a cross-section of a site in a semiconductor wafer;

**Figs. 2A and 2B** illustrate the principles of a direct method according to the invention;

**Fig. 3** illustrates the principles of a reference sites based method according to the present invention;

**Figs. 4-6** illustrate different simulation results of the sensitivity test as functions of grating parameters; and

**Fig. 7** illustrates the effect of an overlay error on a scatterometry signal (diffraction efficiency) as measured on the optimal structure.

## DETAILED DESCRIPTION OF THE INVENTION

Referring to **Fig. 1**, there is schematically illustrated a cross-section of a test site **10** in a semiconductor wafer suitable for use in the present invention. The site **10** contains two gratings (patterned structures) **12** and **14** of certain known periodicity located one above the other. In the present example, the gratings **12** and **14** have substantially the same period **P**. In the present example, the top grating **12** presents a pattern of spaced-apart photoresist-containing regions $\mathbf{R_{PR}}$, and the underneath grating **14** presents a pattern of spaced-apart aluminum-containing region $\mathbf{R_{Al}}$. In this specific example, the gratings **12** and **14** have different duty cycles defined by features critical dimensions $CD_{PR}$ and $DC_{Al}$, respectively. It should, however, be noted that this condition is not a requirement for the technique of the present invention, but provides for a better sensitivity of the method. As further shown in the figure, the gratings **12** and **14** are shifted along the X-axis with respect to each other a distancc **S**, which is measured as a distance between the centers of the two locally adjacent regions (lines) $\mathbf{R_{PR}}$ and $R_{Al}$.

In order to find the conditions under which the method of the present invention is most effective, and show how the method is practical, the sensitivity of the method has been studied for a specific configuration of the site structure exemplified in **Fig. 1**. The site structure **10** is typical for the overlay problem in photoresist-on-aluminum layer structure. The pattern in the aluminum (Al) layer is typically defined by layers underneath the aluminum layer, and the photoresist (PR) layer is patterned by a lithography processing. In this specific example, the PR lines are modeled to be on top of the Al lines. It should, however, be understood, that this is not essential for the present invention, and PR lines may be located between the Al lines, as well. For simplicity, both gratings **12** and **14** have a square profile. The measurement technique used for this analysis is the normal incidence polarized spectrophotometry. According to this technique, the normal incidence reflectivity spectrum is measured with selective polarization direction of the incident light relative to the grating (TM polarization mode in this specific example). Other optical techniques, such as spectral ellipsometry, angular scatterometry, etc. may be used as well.

The sensitivity of the spectrum (measured by the technique of the present invention, which will be described more specifically further below) to a change in the lateral shift $S$ between the gratings **12** and **14** has been studied. The ratio between the mean change in the spectrum (defined as the root of the mean of the square differences between spectra with and without a change in the shift) caused by a change in the shift value $S$ of 1nm has been defined as the sensitivity test $T$, wherein $S$ is the nominal shift.

The simulation results have shown that $T$ depends on all the parameters of the test structure. Values of $T$ are almost always monotonously increasing with the values of $S$. This general rule holds as much as $T$ can be increased, i.e., until the edge of the PR line "falling off" from the Al line. It is thus evident that the measurement is more sensitive for an asymmetrical structure.

As for the other parameters of the test site, such as the period **P**, the $\mathbf{CD_{PR}}$ and $\mathbf{CD_{Al}}$ (generally, the duty cycles of gratings) and the heights $\mathbf{H_{PH}}$ and $\mathbf{H_{Al}}$ of the two

gratings, they usually affect the sensitivity test *T* in an oscillatory manner. It is thus necessary to find such a set of gratings parameters, that *T* is maximized while being least sensitive to the exact values of these parameters. For example, the value of *T* equal to $8\cdot10^{-3}$ is obtained with the following set of gratings' parameters: P=600nm, $CD_{PR}$=300nm, $CD_{AL}$=150nm, $H_{PR}$=600nm, and $H_{AL}$=100nm.

In one embodiment of the invention, the direct method is used. In this method exact simulation methods, such as RCWT (Rigorous Couple Wave Theory), are used to simulate the diffraction signature(s) from the test site. In the simplest case there is not any prior knowledge of the exact grating properties on either layers. In this case the experimentally measured diffraction from the test site is fitted to simulation fitting at the same time for both CD's, grating heights and additional parameters characterizing the individual gratings in the two layers and the shift as an additional fitting parameter.

**Figs. 2 and 2B** exemplify the principles underlying the design of a test site **20** suitable to be used for another embodiment of the present invention. The test site **20** is formed by regions **24** and **26** located one on top of the other in layers $\mathbf{L_1}$ and $\mathbf{L_2}$, respectively. As shown in Fig. 2B, the two regions **24** and **26** define together four different pairs of sub-regions: $\mathbf{A_1}$-$\mathbf{A_2}$, $\mathbf{B_1}$-$\mathbf{B_2}$, $\mathbf{C_1}$-$\mathbf{C_2}$ and $\mathbf{D_1}$-$\mathbf{D_2}$, wherein sub-regions $\mathbf{A_2}$, $\mathbf{B_2}$, $\mathbf{C_2}$ and $\mathbf{D_2}$ are located on top of sub-regions $\mathbf{A_1}$, $\mathbf{B_1}$, $\mathbf{C_1}$ and $\mathbf{D_1}$, respectively. In the pair $\mathbf{A_1}$-$\mathbf{A_2}$, sub-regions $\mathbf{A_1}$ and $\mathbf{A_2}$ are different in that region $\mathbf{A_1}$ contains a grating $\mathbf{G_{A1}}$ and sub-region $\mathbf{A_2}$ has no grating at all, and in the pair $\mathbf{D_1}$-$\mathbf{D_2}$ - *vice versa*. Gratings $\mathbf{G_{B1}}$ and $\mathbf{G_{B2}}$ of sub-regions $\mathbf{B_1}$ and $\mathbf{B_2}$, respectively, are shifted with respect to each other along the X-axis a distance $+\Delta x$ (i.e., in the positive X-direction), and gratings $\mathbf{G_{C1}}$ and $\mathbf{G_{C2}}$ are shifted with respect to each other a distance $-\Delta x$ (negative X-direction). In this embodiment information is gained from measuring the single-grating sites (sub regions $\mathbf{A_1}$-$\mathbf{A_2}$ and $\mathbf{D_1}$-$\mathbf{D_2}$) in order to simplify the fitting in the dual-grating sites (sub regions $\mathbf{B_1}$-$\mathbf{B_2}$ and $\mathbf{C_1}$-$\mathbf{C_2}$). The measurement is done in two steps. In the first step the single-grating sites are measured and the grating characteristics in those sites, including for example CD, height wall angle etc., are measured by fitting to simulation, as in normal

scatterometry. In the second step the measurements of the dual-grating sites are fitted to simulation using all or part of the grating parameters that have been measured in Step 1 and fitting for the shift between the gratings. It should be noted that at least those gratings which are located in a common layer must be are identical, i.e., have the same period, duty cycle, and height.

Notice that for the case of perfect alignment the measurements of sites B and C should be identical, thus a significant difference between the two measurement may indicate an alignment error.The difference between the two signals obtained from sub-region pairs $\mathbf{B_1}$-$\mathbf{B_2}$ and $\mathbf{C_1}$-$\mathbf{C_2}$, respectively, may be utilized in order to increase the sensitivity and reduce systematic measurement errors. This can be done by fitting the difference of simulated signatures to the difference of the measurements in the two sites. This procedure may be used in order to filter out changes in the spectrum that are not related to the shift *S*, thus enhancing the sensitivity and the robustness of the measuring technique.

In another embodiment of the invention, the reference site method is used. **Fig. 3** illustrates the main principles underlying this method. Here, a test site **30**, which is formed by two regions one above the other in layers $\mathbf{L_1}$ and $\mathbf{L_2}$, is composed of a so-called "measurement site" **32** and a so-called "reference site" **34** spaced-apart from each other along the X-axis. Gratings in these sites are not specifically illustrated, but is should be understood that both the measurement and the reference sites include sub-region pairs arranged as described above. In this method, the measurement site **32** has one grating-pair characterized by a nominal shift ($+\Delta X$) between the gratings, and the reference site **34** has several grating-pairs located in sub-region pairs, respectively, aligned in a spaced-apart relationship along the X-axis and characterized by the following nominal shifts: $-\Delta X-3\Delta x$, $-\Delta X-2\Delta x$, $-\Delta X-\Delta x$, $-\Delta X$, $-\Delta X+\Delta x$, $-\Delta X+2\Delta x$, $-\Delta X+3\Delta x$, …etc., $\Delta x$ is typically much smaller than $\Delta X$ and is of the same order of magnitude as the required resolution in the lateral shift measurement. In this method, it is assumed that the grating profiles are sufficiently symmetric and unaffected by the exact shift, and therefore symmetric

shifts between the gratings (upper grating shifted to either right or left of the lower grating) will result in the identical diffraction signatures.

When the two layers are printed with an alignment error ($+\xi$), the actual shifts between the gratings of the measurement site will be: ($+\Delta X+\xi$) and for the reference sites the shifts will be as follows:

($-\Delta X-3\Delta x+\xi$); ($-\Delta X-2\Delta x+\xi$); ($-\Delta X-\Delta x+\xi$); ($-\Delta X+\xi$); ($-\Delta X+\Delta x+\xi$); ($-\Delta X+2\Delta x+\xi$); etc.

In order to measure the alignment error $\xi$, the diffraction signatures from all the sub-region pairs are measured using one of the above mentioned measurement techniques. Then, the signature from the measurement site is compared to the signatures from all the sub-region pairs in the reference site, looking for the best match. If the best match is found for the $(+N)^{'th}$ sub-region pair, for which the nominal shift is ($-\Delta X+N\Delta x$), than we have:

$(+\Delta Xr+\xi)\approx-(-\Delta Xr+N\Delta x+\xi)$

and therefore:

$\xi\approx(-N\Delta x)/2$

Hence, the shift with the resolution of $\Delta x/2$ can be found by simply finding the best matching signature from the set.

If a significant range of shifts is to be covered by a small number of sub-region pairs in the reference site, $\Delta x$ should be selected to be significantly larger than the required resolution. In this case, some interpolation method can be used in order to find the shift with improved accuracy. Interpolation can be done, for example, by calculating the RMS (root mean square) of the difference between the measurement site signature and all reference site signatures, fitting all or part of the results to a polynomial function of the shift and finding the shift providing minimum RMS difference in signatures. Another optional interpolation method is using a learning system, which is trained using the reference site data to return the shift, and measurement site data is used as input for interpretation. Comparing the reference site method to the direct method, the reference site method is advantageously self-calibrating, i.e., there is no need to realize the potentially complex details about how

the diffraction signature was created, including materials properties and exact geometry (e.g. CD, line profile), as long as these are constant for all involved sites. The reference site method, however, requires a larger area on the sample occupied by a test site and a larger number of measurements, requiring more time.

In yet another embodiment of the invention, a calibration method may be used. In this method, a test site similar to the test site **20** of **Figs. 2A** and **2B** (suitable to be used for direct method) but including only two grating-containing sub-region pairs $B_1$-$B_2$ and $C_1$-$C_2$ is used. Here, similarly to the direct method, the difference between the diffraction signatures measured on both sub-region pairs is determined, but, in distinction to the direct method, the resulting signature is not fitted to a theoretical signature, but is rather interpreted using a previously performed calibration stage. In the calibration stage, the signature (or only some sensitive points thereof) is determined as a function of alignment error values, being measured by a suitable reference tool (e.g., ordinary microscope). To this end, a test sample (e.g., semiconductor wafer) is specifically prepared with several alignment shifts, and measured off-line to make a record of the calibration results and keep it as reference data.

In accordance with still another embodiment of the test structure may contain a two-dimensional grating enabling the measurement of the X and the Y components of the lateral shift at the same site. In that case, in order to avoid the possibility to confuse between the X and the Y components further several methods may be used. In accordance with one embodiment, test site is prepared, comprising two dimension grating with a period in the Y-axis significantly different than the period in the X-axis. In accordance with another embodiment polarized reflectometry technique may be used to measure the same site several times with different polarizations. Finally, the same site may be measured from different directions (with different orientation). All the above methods result in different changes to the diffraction signatures due to shifts in different directions, thus avoiding confusion.

Reference is now made to **Figs. 4-6** showing different simulation results of the sensitivity test as functions of grating parameters. **Fig. 4** illustrates the sensitivity

test as a function of **Al** grating depth ($\mathbf{H_{Al}}$) and shift **S** using the test structure of **Fig. 1** with the following parameters: $\mathbf{CD_{PR}}$=150nm, $\mathbf{CD_{Al}}$=300nm, **P**=800nm and $\mathbf{H_{PR}}$=600nm. **Fig. 5** illustrates the sensitivity test as a function of **Al** grating depth ($\mathbf{H_{Al}}$) and grating period **P** using the test structure of the following parameters: $\mathbf{CD_{PR}}$=150nm, $\mathbf{CD_{Al}}$=300nm, $\mathbf{H_{PR}}$=600nm and S=75nm. **Fig. 6** illustrates the sensitivity test as a function of **Al** grating depth using the test structure of the following parameters: $\mathbf{CD_{PR}}$=150nm, $\mathbf{CD_{Al}}$=300nm, P=600nm and $\mathbf{H_{PR}}$=600nm. Two graphs **R1** and **R2** are shown corresponding, respectively, to TM and TE polarization modes of incident radiation relative to the grating orientation.

**Fig. 7** illustrates the effect of a 5nm overlay error on a scatterometry signal (diffraction efficiency) measured on the optimal structure with the TM polarization mode. Two diffraction signatures $\mathbf{SG_1}$ and $\mathbf{SG_2}$ are shown corresponding, respectively, to a sample with no lateral shift between the layers (i.e., overlay is zero) and to a sample with a 5nm overlay error.

Obviously, many modifications and variations of the present invention are possible in the light of the above teachings. For example, in the reference site based method grating-pairs located in sub-region pairs may be characterized by pre-determined arbitrary nominal shifts.

Those skilled in the art will readily appreciate that many modifications and changes may be applied to the invention as hereinbefore exemplified without departing from its scope, as defined in and by the appended claims.

**CLAIMS:**

**1.** A method for controlling layers alignment in a multi-layer sample, the method comprising the steps of:

(i) providing a measurement site including two regions located one above the other in two different layers, respectively, said regions containing patterned structures of a certain known periodicity;

(ii) illuminating said site with electromagnetic radiation and detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures.

(iii) analyzing said diffraction efficiency to determine an existing lateral shift between the layers.

**2.** The method of claim 1, wherein said pattern structures characterized by substantially the same periodicity.

**3.** The method of claim 2, further comprising the step of providing at least one additional site including two regions located one above the other in two different layers, respectively, respectively, said regions containing patterned structures; illuminating said additional site with electromagnetic radiation and detecting diffraction efficiency of radiation diffracted from the patterned structures and analyzing the diffraction efficiencies obtained in said sites to determine an existing lateral shift between the layers.

**4.** The method of claim 3, wherein the pattern structures located in two different layers of the measurement site are shifted with respect to each other along the X-axis by a distance $+\Delta X$ and the pattern structures located in two different layers of the additional site are shifted with respect to each other along the X-axis by a distance $-\Delta X$.

**5.** The method of claim 4 further comprising the step of providing additional sites including regions containing pattern structures in one of the layers.

**6.** The method of claim 3 wherein the pattern structures located in two different layers of the measurement site are shifted with respect to each other along

the X-axis by a distance $+\Delta X$ and the pattern structures located in two different layers of the additional sites are shifted with respect to each other along the X-axis by a distance $-\Delta X \pm N\Delta x$, wherein $\Delta x \ll \Delta X$ and N is an integer number.

**7.** The method of claim 1 wherein said detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures comprising measuring said diffraction efficiency as a function of wavelength.

**8.** The method of claim 1 wherein said detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures comprising measuring said diffraction efficiency as a function of angle of incidence.

**9.** The method of claim 1 wherein said detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures comprising measuring said diffraction efficiency as a function of angle of reflection.

**10.** The method of claim 1 wherein said detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures comprising measuring said diffraction efficiency as a function of angle of incidence and angle of reflection.

**11.** The method of claim 1 wherein said detecting a diffraction efficiency of radiation diffracted from the patterned structures indicative of a lateral shift between the patterned structures comprising measuring said diffraction efficiency as a function of change of polarization amplitude and phase of the diffracted light

**12.** The method of claim 3, wherein at least one of additional sites comprising pattern structures at essentially right angle to the pattern structures of the measurement site.

**13.** The method of claim 1 wherein the step of illuminating said site with electromagnetic radiation comprising illuminating with polarized light with different states of polarization.

14. The method of claim 1 wherein said patterned structures are two-dimensional.

15. The method of claim 14 wherein period of said two-dimensional patterned structures is different along the X-axis and Y-axis.

16. The method of claim 14 wherein the step of illuminating said site with electromagnetic radiation comprising illuminating with polarized light with different states of polarization.

17. The method of claim 1 wherein said multi-layer sample is semiconductors wafer.

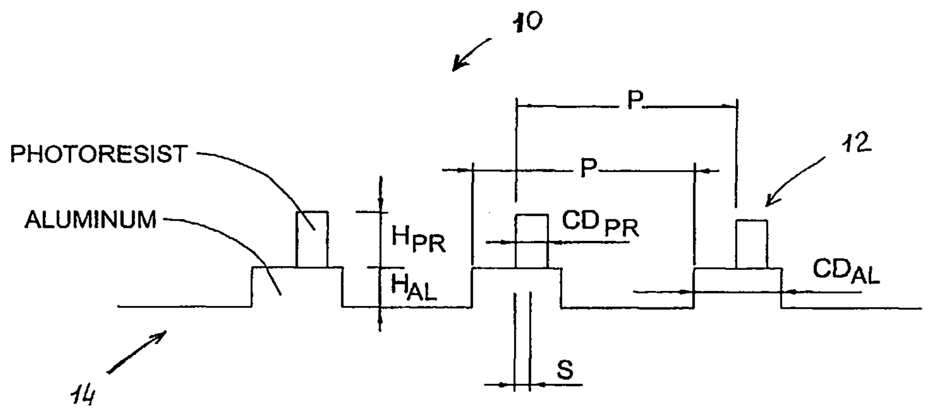

10
P
P
12
PHOTORESIST
ALUMINUM
$H_{PR}$
$CD_{PR}$
$H_{AL}$
$CD_{AL}$
S
14

FIG. 1

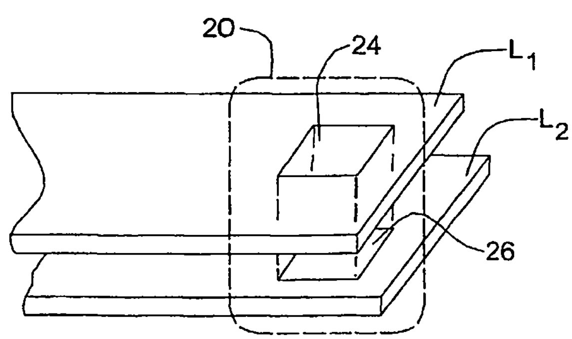
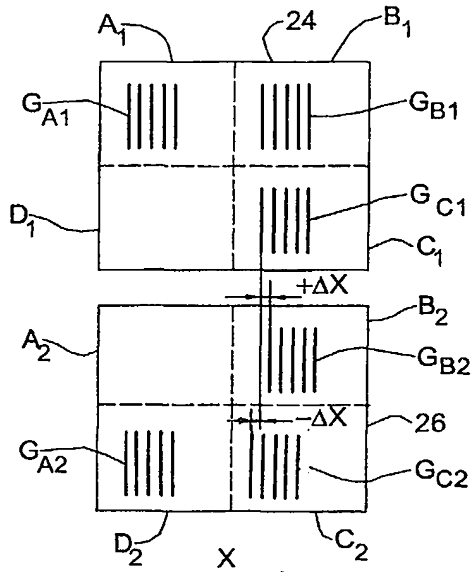

20
24
$L_1$
$L_2$
26

FIG. 2A


A1
24
B1
GA1
GB1
GC1
D1
C1
+ΔX
B2
A2
GB2
-ΔX
26
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D2
C2
X

FIG. 2B

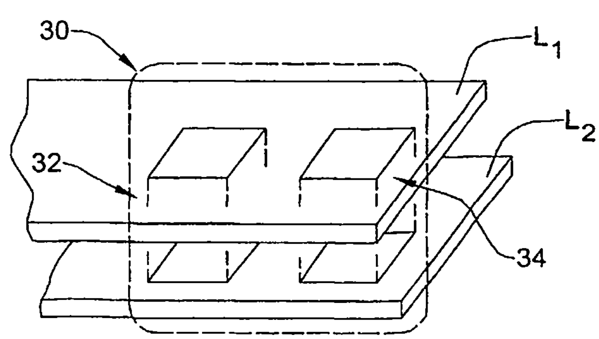

30
L1
L2
32
34

FIG. 3

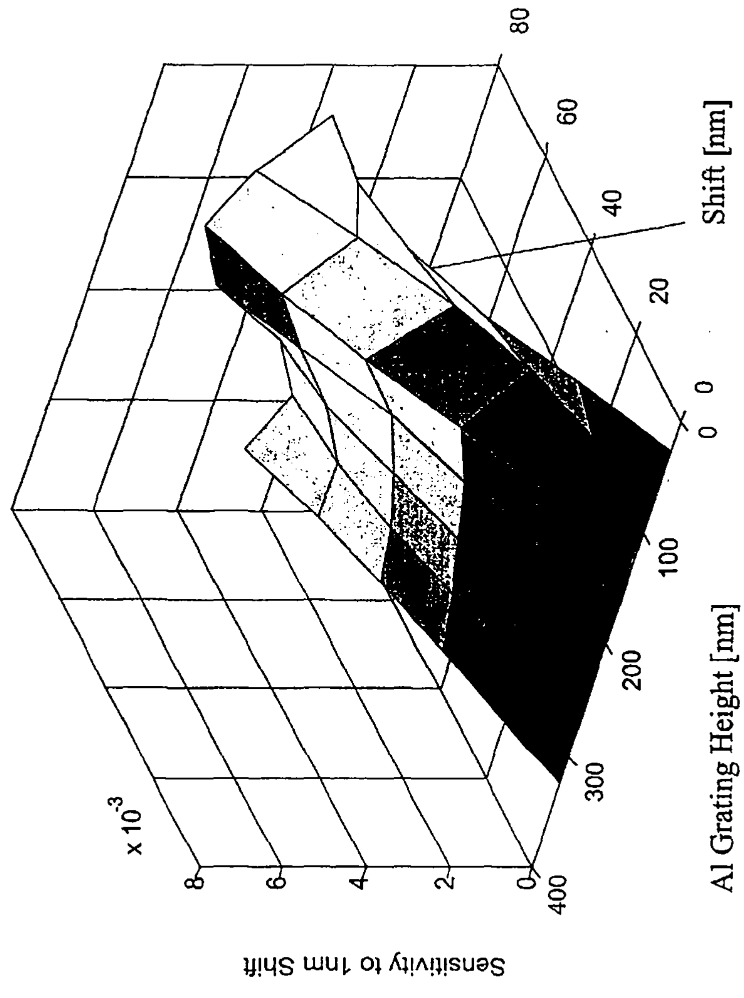
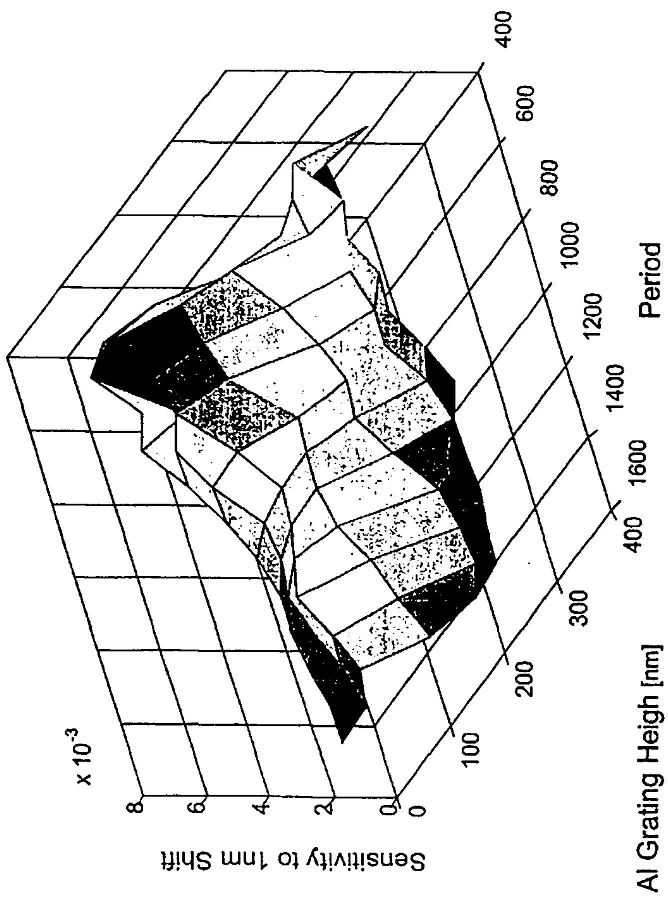

Sensitivity to 1nm Shift
x $10^{-3}$
8
6
4
2
0
400
300
200
100
0
0
20
40
60
80
Al Grating Height [nm]
Shift [nm]

FIG. 4



x 10-3
Sensitivity to 1nm Shift
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2
4
6
8
0
100
200
300
400
Al Grating Heigh [nm]
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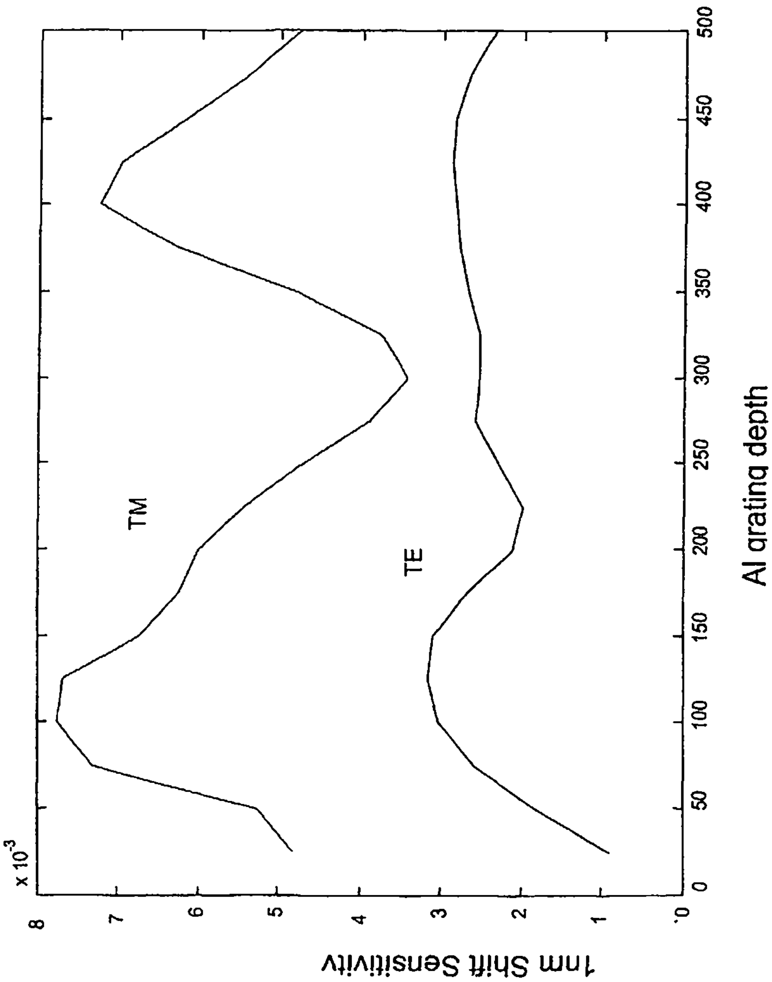
600
800
1000
1200
1400
1600
Period


FIG. 5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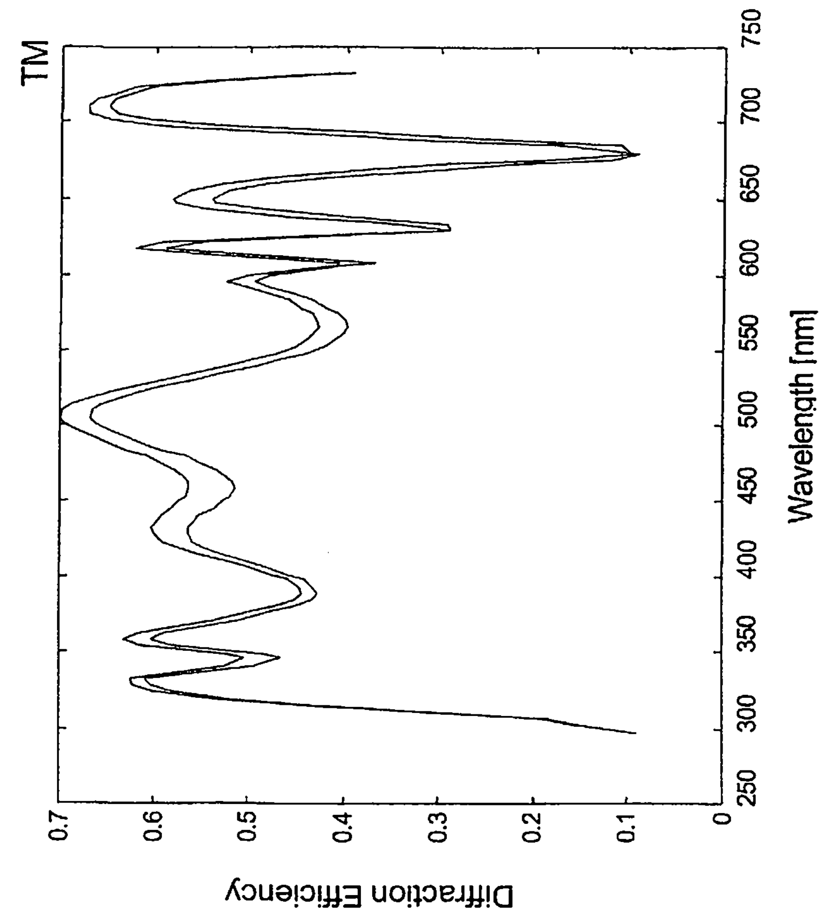
2
3
4
5
6
7
8

FIG. 6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Diffraction Efficiency
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
250
300
350
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450
500
550
600
650
700
750
Wavelength [nm]

FIG. 7